Addressing the Training Gap for Ammonia-Fuelled Propulsion Systems: A Literature Review and Proposal for a New Job Training Program

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Abstract
The maritime industry is increasingly turning to ammonia as a promising alternative marine fuel to achieve sustainable and environmentally friendly shipping practices. However, this transition presents operational challenges and safety concerns that necessitate specialized training for marine engineers. This literature review examines the existing research on ammonia's operational challenges and identifies a critical research gap - the lack of comprehensive training programs for marine engineers to handle ammonia-fuelled propulsion systems effectively. The review highlights the importance of theoretical knowledge and practical training in such programs to ensure safe and efficient operations. Additionally, the study analyzes current training initiatives provided by leading maritime education institutions, Det Norske Veritas (DNV) Energy Academy, Lloyd's Maritime Academy, and Maritime Training Academy, to derive insights for developing a new job training program on ammonia-fuelled propulsion ships. The proposed program encompasses theoretical lectures and practical hands-on experiences, empowering marine engineers to navigate ammonia as a fuel source proficiently. By addressing this research gap and providing specialized training, the maritime industry can facilitate a smooth transition to ammonia as a marine fuel, promoting reduced environmental impacts and enhanced operational efficiency in the shipping sector. This literature review and proposal aim to contribute to the ongoing efforts in achieving sustainable and responsible maritime practices in the context of ammonia as a promising alternative marine fuel.

Keywords: Ammonia propulsion, Marine engineering, Sustainable maritime practices, effective training initiatives, Environmental sustainability, Operational complexities.

Introduction

Ammonia has emerged as a promising marine fuel, offering a potential solution for bridging the gap between short-term environmental objectives set by the International Maritime Organization (IMO) and the eventual complete replacement of carbon-rich fuels to ensure a sustainable future for shipping (Yadav & Jeong, 2022). The appeal of ammonia lies in its carbon-free nature, presenting an eco-friendly alternative when considered on an economic scale (Machaj et al., 2022). Particularly in the shipping industry, ammonia demonstrates advantages over hydrogen, another zero-carbon fuel, due to its ease of handling and storage (Gerlitz et al., 2022).

However, the adoption of ammonia as fuel raises concerns about reduced thermodynamic engine efficiency, leading to higher energy consumption compared to traditional diesel fuel (Rodríguez et al., 2022). Ammonia's potential energy is only about half that of MGO (Gerlitz et al., 2022). Additionally, the safety implications of using ammonia as fuel differ from those associated with conventional fuels, given its toxic, corrosive, and flammable properties (Duong et al., 2023). The transportation and onboard utilization of ammonia also pose risks of exposure (Wang et al., 2023). Nonetheless, the advantages of green ammonia, including its carbon-free nature, relatively high-volume energy density, and ease of storage and transportation, continue to garner favorable attention (Tornatore et al., 2022).

In 2015, the International Convention for the Safety of Life at Sea (SOLAS) was updated to allow for the use of low flashpoint fuels, with ships required to comply with the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code). The IGF Code outlines regulations and functional requirements for the design, construction, operation, maintenance, bunkering process, and seafarer training related to ships utilizing low flashpoint fuels, emphasizing safe operation and navigation (Wang et al., 2023). However, specific design requirements for ammonia-fueled ships have not been addressed in the IGF Code (Yadav & Jeong, 2022), necessitating tailored amendments to accommodate the unique

characteristics of ammonia as a marine fuel (Cheliotis et al., 2021).

This study critically examines existing overseas job training initiatives focused on ammonia-fueled propulsion ships and proposes specialized courses for marine engineers dedicated to mastering ammonia-fueled propulsion systems. The recommended courses strike a balance between theoretical knowledge and practical training, empowering marine engineers to enhance their expertise and understanding of ammonia-fueled propulsion ships. By addressing the training gap in handling ammonia as a marine fuel, this research aims to facilitate a smooth and safe transition to sustainable shipping practices, reducing environmental impacts in the maritime industry.

The objective of this literature review is to examine the training gap for marine engineers operating ammonia-fueled propulsion systems and propose a new comprehensive job training program to address this gap. To achieve this objective, this literature review will explore a wide range of academic research articles, industry reports, and case studies related to the use of ammonia as a marine fuel. The review will also delve into training and education programs currently in place, both in academic institutions and within the maritime industry, to ascertain the extent to which they adequately prepare engineers for the specific demands of ammonia propulsion systems.

This review is delimited in scope to the precise identification of training necessities and essential competencies necessary for marine engineers to proficiently and securely operate ammonia-fueled propulsion systems. In focusing on this specific aspect, the aim is to pinpoint the exact requirements and knowledge areas that are essential to ensure the safe and efficient operation of such advanced propulsion technology in the maritime sector. By honing in on these critical training needs and competencies, this review will contribute to the development of targeted and effective training programs, thereby addressing a key component of the broader transition toward more environmentally sustainable and technologically advanced marine propulsion systems.

Overview of Ammonia-Fueled Propulsion Systems

Ammonia-fueled propulsion systems are gaining interest as a potential carbon-free fuel for transportation and energy production (Kobayashi et al., 2019; Ma et al., 2023; Machaj et al., 2022; Tornatore et al., 2022; Valera-Medina et al., 2021; Xu et al., 2022). Ammonia is a molecule that can be synthesized from renewable energy sources and has a high energy density, making it a promising alternative to fossil fuels (Valera-Medina et al., 2021). Here is an overview of ammonia-fueled propulsion systems:

Advantages of ammonia fuel: Ammonia is a carbon-free fuel that can be produced from renewable energy sources, making it a promising alternative to fossil fuels. It has a high energy density, which means it can store more energy per unit volume than other fuels like hydrogen. Ammonia is also easier to transport and store than hydrogen because it can be stored as a liquid at room temperature and atmospheric pressure (Kobayashi et al., 2019; Ma et al., 2023; Machaj et al., 2022; Tornatore et al., 2022; Valera-Medina et al., 2021; Xu et al., 2022).

Challenges of ammonia fuel: Ammonia has a low flame speed, which means it burns slowly and requires high boost pressure and compression ratio to compensate. It also has a high ignition temperature, which makes it difficult to ignite in internal combustion engines. Ammonia is also toxic and corrosive, which requires special handling and storage procedures (Kobayashi et al., 2019; Ma et al., 2023; Tornatore et al., 2022).

Ammonia-fueled engines: There are two types of ammonia-fueled engines: pure ammonia-fueled engines and ammonia-blended engines. Pure ammonia-fueled engines have been developed and tested, but they have limitations due to the challenges mentioned above. Ammonia-blended engines, which use a mixture of ammonia and other fuels like hydrogen or diesel, are more feasible and have been shown to reduce emissions (Ma et al., 2023; Xu et al., 2022).

Research and development: There is ongoing research and development on ammonia-fueled propulsion systems, including combustion technology, engine design, and fuel storage and handling. The goal is to overcome the challenges of ammonia fuel and make it a viable alternative to fossil fuels (Kobayashi et al., 2019; Ma et al., 2023; Tornatore et al., 2022).

In conclusion, ammonia-fueled propulsion systems have the potential to be a carbon-free alternative to fossil fuels. While there are challenges to overcome, ongoing research and development are making progress towards making ammonia fuel a viable option for transportation and energy production.

Lack of Effective Training on Ammonia-Fuelled Propulsion

The growing interest in ammonia as a sustainable and environmentally friendly marine fuel has garnered significant attention in recent years. Several studies have shed light on the technical and safety challenges associated with ammonia-fuelled propulsion systems (Agocs et al., 2023; Wang et al., 2023). However, a critical research gap becomes evident when reviewing the literature - the lack of emphasis on effective training and preparedness of marine engineers to effectively handle and operate ammonia-fuelled propulsion systems.

According to a bibliometric review and research agenda, a significant number of maritime accidents are primarily caused by deficiencies in knowledge, often attributed to a lack of experience, and inadequate training, with human error playing a pivotal role (Dominguez-Péry et al., 2021). Inadequate effective

training can directly lead to accidents, particularly when heavy machinery is operated on ships or within harbor settings, potentially resulting in cargo load collapses and risks to workers below (Inadequate Training Accidents - Maritime Injury Center, n.d.). Applying the HFACS framework for incident analysis reveals that insufficient supervision from shore-based management is a major contributor to casualties and incidents. This encompasses failures to ensure the deployment of qualified personnel aboard vessels and to guarantee proper training in Safety Management Systems, equipment, and systems (Batalden & Sydnes, 2014). Therefore, comprehensive and effective training for maritime industry workers is essential, not only equipping them with job-specific skills but also instilling a deep understanding of safety protocols and equipment use. This approach can significantly mitigate risks, enhance safety standards, and reduce accidents in these high-risk work environments (Inadequate Training Accidents - Maritime Injury Center, n.d.).

In their research, Karvounis et al., (2022) have pinpointed certain areas that require further investigation. One notable aspect is the exploration of digital representations and the application of machine learning techniques and tools. These advancements aim to facilitate the effective, secure, and environmentally conscious functioning of ship power plants that utilize alternative fuels. Embracing these technologies can lead to significant improvements in the maritime industry's transition towards sustainable and eco-friendly practices.

Shim et al., (2023) anticipate a transformation in propulsion power sources, with a shift towards carbon-neutral fuels in the near future. They emphasize the increasing prevalence of electric/hybrid propulsion systems capable of accommodating diverse power sources. To validate the effectiveness, reliability, and safety of these various carbon-neutral technologies in the maritime domain, there is a crucial need for comprehensive demonstrations and evaluations.

Ammonia, as discussed by Duong et al., (2023), presents unique challenges in terms of safe handling procedures, storage requirements, and risk assessment. These challenges underscore the need for specialized effective training programs dedicated to equipping marine engineers with the necessary knowledge and skills. Unfortunately, the existing literature falls short in providing comprehensive effective training programs tailored explicitly to address the operational challenges of ammonia-fuelled propulsion ships.

Closing this training gap assumes paramount importance in ensuring the successful integration of ammonia as a marine fuel. Well-trained marine engineers will play a pivotal role in minimizing operational risks and maximizing the environmental and economic benefits of ammonia utilization in the maritime industry (Yadav & Jeong, 2022). Competence-based training programs should focus on critical areas, including fuel system maintenance, monitoring, troubleshooting, and emergency response in ammonia-related incidents (Duong et al., 2023).

Through well-designed effective training courses, marine engineers will be equipped with the expertise and confidence required to handle ammonia-fuelled propulsion systems safely and efficiently. This aligns with Duong's (2023) call for enhanced training and preparedness to meet the demands of a technology-driven market and a complex regulatory landscape.

The research methodology adopted for this study involved a systematic review of the available literature. This encompassed an extensive exploration of existing training programs, the identification of barriers, and an in-depth examination of research pertaining to the use of ammonia as a fuel source. In total, 17 relevant studies were rigorously analyzed to gain valuable insights and evaluate ongoing initiatives. The review extended to a meticulous investigation of course structures, content, and assessment methods, with the resulting compilation of this information serving as a foundational resource for the development of the proposed module.

Existing training programs related to handling, storing and operating ammonia.

Ammonia has emerged as a promising alternative marine fuel, offering carbon-free properties and potential for a sustainable shipping future. However, its safe handling, storing, and operational aspects pose challenges, necessitating comprehensive training programs for marine professionals. In this context, this article delves into the existing training initiatives provided by leading maritime education institutions, Det Norske Veritas (DNV) Energy Academy, Lloyd's Maritime Academy, and Maritime Training Academy, focusing on their specialized courses that equip learners with in-depth knowledge and expertise in safely managing ammonia as a marine fuel.

DNV Energy Academy

The DNV Energy Academy stands at the forefront of empowering professionals in the rapidly evolving energy industry, offering specialized training programs designed to equip participants with essential knowledge and expertise. Specifically, their comprehensive course titled "Role of Ammonia in a Hydrogen Economy" delves into the critical aspects of ammonia's role as a hydrogen carrier and its potential to drive a greener future.

DNV Energy Academy offers comprehensive training sessions covering various aspects of ammonia as a hydrogen carrier, as outlined in Table 1 on their website (dnv.com). The training program is highly flexible and can be tailored to be conducted either onsite or online, comprising of two half-day blocks (4 hours) divided into four modules. The training

curriculum encompasses the value chain, market analysis, economics, technological advancements, and safety considerations in operations. Upon review, it becomes evident that the course can be predominantly focused on theoretical aspects.

Overall, the "Role of Ammonia in a Hydrogen Economy" course offered by DNV Energy Academy enables professionals to stay ahead of the curve in the energy industry's ongoing transition. By providing specialized knowledge and training, DNV Energy Academy empowers individuals to play a pivotal role in driving sustainable and innovative solutions in the ammonia and hydrogen energy sectors.

Table 1 'Role of ammonia in a hydrogen economy' course syllabus at DNV Energy Academy

Module	Topics and subtopics
1	Understanding the green ammonia value chain - Production, transportation, storage and utilization - Carbon free ammonia - value chain - Possible hydrogen carriers - comparing different carriers - Market players - drivers, barriers, challenges
2	Technology & cost - Green power production - Hydrogen production - Ammonia production - ammonia synthesis -Ammonia transmission / storage - Ammonia decomposition - Hydrogen distribution
3	Operational safety - Ammonia properties - Safe design and operation - Toxic and highly corrosive - Personal protective equipment - Regulation and standards
4	End-use challenges - Ammonia as fuel - Hydrogen as fuel - Challenges with the combustion of ammonia - Ammonia as feedstock - Developing new combustion concepts

Source: (Training course Role of ammonia in a hydrogen economy, n.d.)

Lloyd's Maritime Academy

As a leading institution in maritime education, Lloyd's Maritime Academy is committed to providing learners with comprehensive and interactive programs that foster accelerated learning. Their "Certificate in Alternative Fuels" course as outlined in Table 2 is no exception, offering a structured and engaging learning experience to equip professionals with expertise in the field of alternative marine fuels.

With a focus on convenience and flexibility, the course is designed as a single module that can be completed within six months. Learners benefit from a diverse range of learning activities, including online instructional materials, interactive forums to connect with peers and facilitators, investigation of real-world case studies, and practical application of knowledge through ongoing project submissions.

The course delves deep into the realm of alternative marine fuels, addressing the complex and evolving regulations on emissions. As shipping companies face increased demands to improve processes and remain competitive, the use of alternative fuels emerges as a strategic technique to meet environmental standards, enhance efficiency, and reduce costs.

Throughout the program, participants take a close look at a variety of new fuel alternatives, including LPG, methanol, hydrogen, and ammonia. These alternatives not only align with current and future restrictions but also offer potential for sustainable and cost-effective maritime operations.

Lloyd's Maritime Academy continues to empower learners with a comprehensive and interactive learning journey, fostering the growth of professionals as leaders in sustainable shipping practices and driving the industry towards a greener and more efficient future.

Table 2 'Certificate in Alternative Fuels' course syllabus at Lloyd's Maritime Academy

Module	Topics and subtopics
1	Introduction to Alternative Fuels - Definitions, rationale, background - Why are alternative fuels required? - What are the various alternative fuels available? - Fuel challenges in shipping - Various stakeholders and their work - Challenges
2	Regulations - Air pollution from shipping and IMO - IGC Code for LNG carriers – an overview - IGF Code for other ships – an overview - Greenhouse gas (GHG) emissions - sulphur oxides (SOx), nitrogen oxides (NOx), particulate matter (PM)
3	Alternative Fuel Options - Short summary of various alternative fuels - Comparison between alternative fuels

	- Renewable sources - LNG/ LPG/ methanol/ biofuels/ hydrogen/ ammonia/ nuclear - Not just fuel – solar, wind, wave
4	LNG - LNG as a marine fuel - Technology involved in LNG containment systems - Safety systems associated with LNG fuel - Environmental impact of LNG as fuel - Commercial aspects associated with using LNG as fuel - Bunkering of LNG and latest news on LNG bunkering
5	LPG, Biofuels - LPG as a marine fuel - The various biofuels available – methanol, Fatty Acid Methyl Ester (FAME), Hydrogenation-derived renewable diesel (HDRD), Dimethyl Ether (DME), biomass-to-liquid (BTL), gas-to-liquid (GTL), Liquefied Bio Gas (LBG) - Methanol as a marine fuel - Technology associated with LPG fuel & methanol fuel - Safety and the environmental impact of LPG & methanol - Commercial aspects and bunkering of LPG & methanol
6	Hydrogen & Ammonia - Use of hydrogen as a marine fuel - Fuel cells, batteries - Ammonia as a marine fuel, latest news - Technology, safety, environmental impact, commercial aspects associated with hydrogen and ammonia
7	Nuclear & Renewable Energy - Nuclear energy as a marine fuel - Various renewable energy sources, e.g., solar PV, wind (sails, rotors, turbines etc.), waves - Technology, safety, commercial aspects involved in the use of renewable sources

Source: (Certificate in Alternative Fuels | Lloyd's Maritime Academy, n.d.)

Maritime Training Academy

In the dynamic realm of the maritime industry, sustainable practices and alternative marine fuels have emerged as paramount concerns. The Maritime Training Academy, known for its commitment to excellence in maritime education, offers a specialized online course, "Certificate in Alternative Fuels," as it is in Table 3 tailored to equip professionals with profound knowledge in this critical domain. This comprehensive program delves deeper into the subject of alternative marine fuels, providing participants with a holistic understanding of the advantages, disadvantages, hazards, properties, evolution, and basic operational criteria of these innovative fuel sources.

Structured as a single module, the course allows participants the flexibility to complete it within six months, accommodating their busy schedules. The module itself is thoughtfully designed, incorporating engaging text, charts, and pictures, ensuring a rich and immersive learning experience. Moreover, the program includes ten multiple-choice questions, serving as a valuable assessment tool, with participants expected to achieve a minimum passing score of 70%.

For professionals seeking to stay ahead in the ever-evolving maritime landscape, the "Certificate in Alternative Fuels" course at Maritime Training Academy provides a transformative educational experience, empowering them to champion sustainable practices and foster a future of responsible marine fuel utilization.

Table 3 'Certificate in Alternative Fuels' course syllabus at Maritime Training Academy

Module	Topics and subtopics
1	Liquid Natural Gas (LNG)
2	Hydrogen and Marine Systems
3	Methanol and Biomethane and Marine Systems
4	Biomethane (Biogas)
5	(Bio) Ethanol
6	Biodiesel
7	Ammonia
8	Battery-powered Marine Systems
9	Alternative Marine Fuels (Advantages & Disadvantages) – Summary

Source: (Alternative Marine Fuels - Maritime Training Academy, n.d.)

The maritime industry is witnessing a growing demand for comprehensive training programs focused on handling, storing, and operating ammonia as a sustainable marine fuel. DNV, Lloyd's Maritime Academy, and Maritime Training Academy have each developed specialized courses, equipping professionals with in-depth knowledge and practical skills to ensure the safe and efficient utilization of ammonia. With a collective commitment to fostering a greener and more responsible maritime future, these esteemed institutions play a vital role in empowering learners with the expertise needed to navigate the complexities of alternative marine fuels, contributing to a more sustainable and environmentally conscious shipping industry.

Critique of Existing Programs

While institutions like DNV Energy Academy, Lloyd's Maritime Academy, and Maritime Training Academy offer courses related to ammonia as a marine fuel, these programs fail to adequately address the identified training gap for marine engineers handling ammonia-fueled propulsion systems.

For instance, the course offered by DNV Energy Academy provides a strong theoretical foundation on the ammonia value chain, market analysis, and safety considerations. However, the heavy focus on lectures creates a knowledge-driven rather than competency-driven program. The course lacks sufficient practical exercises and simulations to instil skills in critical areas like fuel system maintenance, hands-on ammonia handling, and emergency response (Training course Role of ammonia in a hydrogen economy, n.d.).

Similarly, Lloyd's Maritime Academy's course covers regulatory compliance, properties of ammonia, and environmental impacts through online modules and case studies. But the program does not incorporate immersive simulations and field experience for trainees to develop proficiency in tasks like troubleshooting fuel systems, maintaining safe storage conditions, and managing incidents (Certificate in Alternative Fuels | Lloyd's Maritime Academy, n.d.).

While the Maritime Training Academy's course explores various alternative fuels, it dedicates only one module to ammonia. This narrow coverage is insufficient to provide comprehensive training across the range of competencies needed for ammonia-fueled propulsion system operations (Alternative Marine Fuels - Maritime Training Academy, n.d.).

In summary, current training initiatives provide a starting point but lack the depth and rigor required to address the identified gap. A truly competency-based program with intensified practical components is needed to produce marine engineers who are experts in handling ammonia safety, fuel system optimization, and emergency preparedness. The proposed job training program in this paper aims to fulfil this need.

Development of a job-training course model on ammonia fuelled propulsion ship

A comparative document analysis was conducted to systematically review and evaluate the existing job training programs offered by DNV Energy Academy, Lloyd's Maritime Academy, and Maritime Training Academy. This allowed insights to be derived for developing the proposed job training course model.

The course syllabi and materials from each training program were obtained and analyzed using a structured framework. Key aspects that were compared included the topics covered, number of lecture and practical hours allocated, learning outcomes and assessment methods.

From DNV Energy Academy's 'Role of Ammonia in a Hydrogen Economy' course, theoretical modules on the ammonia value chain, technological aspects, and safety considerations informed the inclusion of similar content areas in the proposed model.

Lloyd's Maritime Academy's 'Certificate in Alternative Fuels' covered a wide range of fuel types and regulatory issues. This guided the decision to incorporate modules on fuel properties, handling protocols, and compliance with international standards.

Maritime Training Academy's focus on individual fuel technologies through dedicated modules aided the structuring of topics in the proposed model, seen in Table 1.

The practical components of each program were also evaluated based on activities, intended skills and assessment criteria. This supported the design of hands-on modules encompassing simulation exercises, system maintenance workshops and onboard experience.

By conducting a systematic comparison of existing training programs through document analysis, key elements were identified and synthesized to develop an integrated course model addressing identified gaps. This helps to ensure the proposed model provides a rigorous and tailored job training experience.

Proposed New Job Training Programme.

As the maritime industry strives to transition towards greener and more sustainable practices, the use of ammonia as a marine fuel has emerged as a promising solution. Embracing this paradigm shift requires a skilled workforce equipped with the knowledge and proficiency to operate ammonia-fuelled propulsion ships safely and efficiently. In response to this demand, we present our proposed Job Training Programs for Operation of Ammonia-Fuelled Propulsion Ships. This comprehensive competence-based training model is designed to empower learners with the essential theoretical understanding and practical skills needed to navigate the complexities of ammonia as a fuel source. Through a structured curriculum comprising lecture and practical hours, learners will gain insights into the properties of ammonia, handling and safety protocols, regulatory compliance, ammonia fuel systems, and operational considerations. The program culminates with immersive practical experiences that reinforce learners' proficiency in ammonia handling, system maintenance, emergency response, and collaborative problem-solving. Join us on this transformative journey towards a greener maritime future, where ammonia becomes a catalyst for change in the propulsion of our vessels.

Table 4. Proposed Training for Masters, Officers, Ratings and Other Personnel on Ships Subject to Ammonia as Marine Fuel

Subject Area	Hours		Assessment Criteria: Knowledge (K); Understanding (U); Proficiency (P)
	Lecture	Practical	
Theoretical section 1. Introduction to Ammonia as a Marine Fuel 1.1 Properties and characteristics of ammonia as a fuel 1.2 Advantages and challenges of using ammonia in marine propulsion 1.3 Environmental impact and emissions reduction potential of ammonia	6	-	K: Written examination on properties, advantages, and environmental impact of ammonia as a fuel. U: Group discussion on the challenges and potential of using ammonia in marine propulsion. P: not appliable (N/A)
2. Ammonia Handling and Safety 2.1 Safe handling procedures and best practices 2.2 Storage requirements and safety measures for ammonia fuel 2.3 Risk assessment and mitigation strategies for ammonia operations	9	6	K: Quiz on safe handling procedures and storage requirements for ammonia. U: Practical assessment of safe handling techniques through simulation exercises. P: Simulation-based assessment of risk assessment and response actions in ammonia-related emergencies.
3. Regulatory Compliance 3.1 International regulations and standards for ammonia-fuelled ships 3.2 Compliance with safety and environmental guidelines	3	-	K: Multiple-choice questions on international regulations for ammonia-fuelled ships. U: Case study on compliance with safety and environmental guidelines. P: N/A
4. Ammonia Fuel Systems 4.1 Components and infrastructure of ammonia fuel systems 4.2 Onboard fuel processing and delivery mechanisms 4.3 Performance optimization and efficiency considerations	6	6	K: Written examination on ammonia fuel system components and performance optimization. U: Practical assessment of onboard fuel processing and delivery mechanisms. P: Hands-on evaluation of performance optimization and efficiency considerations.
Operational Aspects: 5. Operational Considerations for Ammonia-Fuelled Propulsion 5.1 Operational best practices for ammonia-fuelled propulsion	3	6	K: Quiz on operational best practices for ammonia-fuelled propulsion. U: Practical assessment of operational considerations through simulation exercises. P: Onboard observation of learners applying theoretical knowledge to actual ship operations.
6. Fuel System Monitoring and Troubleshooting 6.1 Monitoring and troubleshooting of ammonia fuel systems	3	6	K: Multiple-choice questions on fuel system monitoring and troubleshooting. U: Practical assessment of monitoring and troubleshooting techniques. P: Onboard evaluation of learners' ability to identify and resolve potential challenges.
Practical Section: 7. Hands-on Ammonia Handling 7.1 Safe handling techniques through simulation exercises 7.2 Real-life scenarios to develop practical ammonia handling skills	-	12	K: N/A U: Practical assessment of safe handling techniques and responses to real-life scenarios. P: Hands-on evaluation of learners' practical ammonia handling skills.
8. Ammonia Fuel System Maintenance	-	12	K: N/A

8.1 Inspection, maintenance, and troubleshooting of ammonia fuel systems 8.2 Identification and resolution of potential challenges			U: Practical assessment of fuel system maintenance and troubleshooting. P: Hands-on evaluation of learners' ability to identify and resolve potential challenges.
9. Emergency Response Training 9.1 Simulation-based emergency response training for ammonia incidents 9.2 Prompt and effective response actions in ammonia-related emergencies	-	12	K: N/A U: Simulation-based assessment of learners' emergency response skills. P: Evaluation of prompt and effective response actions in ammonia-related emergencies.
10. Onboard Ammonia Operation 10.1 Real-world experience in managing ammonia fuel system on board ships 10.2 Application of theoretical knowledge to actual ship operations	-	12	K: N/A U: Onboard observation of learners applying theoretical knowledge practically. P: Evaluation of learners' competence in managing ammonia fuel systems on board ships.
11. Collaborative Projects 11.1 Design, implementation, and evaluation of ammonia fuel system solutions 11.2 Collaborative problem-solving and teamwork	-	12	K: N/A U: Assessment of collaborative problem-solving and teamwork skills. P: Evaluation of learners' ability to design, implement, and evaluate ammonia fuel system solutions collaboratively.

***Note**: The assessment criteria for each module include knowledge-based assessments (written examinations, quizzes), understanding-based assessments (group discussions, case studies), and proficiency-based assessments (practical evaluations, onboard observations). The total practical hours for the entire training program are 84 hours, distributed across different modules for hands-on learning and real-world experience.*

The proposed Competence-Based Training Program on Ammonia-Fuelled Propulsion Ships is a comprehensive and structured curriculum designed to equip maritime professionals with the necessary knowledge, understanding, and proficiency to operate ammonia-fuelled ships safely and efficiently. Through a combination of theoretical lectures and practical hands-on training, learners will delve into the properties and characteristics of ammonia as a fuel, explore its advantages and challenges in marine propulsion, and understand its environmental impact and emissions reduction potential. Safety and regulatory compliance are emphasized through simulations and case studies, ensuring learners are adept at safe handling, risk assessment, and mitigation strategies. Moreover, learners will gain in-depth insights into ammonia fuel systems, performance optimization, and operational best practices. The practical section of the program offers immersive experiences in ammonia handling, fuel system maintenance, emergency response, and collaborative projects, fostering hands-on proficiency and teamwork. By undertaking this training, maritime professionals will be at the forefront of driving sustainable practices in the shipping industry, contributing to a cleaner and greener future for our oceans and the planet as a whole.

Conclusion

The transition to ammonia as a marine fuel holds great promise for a sustainable shipping future, as it offers a carbon-free alternative with relatively easy handling and storage conditions. However, challenges in terms of reduced thermodynamic efficiency and safety concerns pose significant obstacles. To overcome these challenges, specialized and effective training for marine engineers is essential. The literature review highlighted the research gap in the existing literature, emphasizing the lack of focus on training and preparedness of marine engineers to handle ammonia-fuelled propulsion systems effectively.

The existing literature calls for comprehensive training programs tailored specifically to address the operational challenges of ammonia-fuelled propulsion ships. Such training programs should cover areas such as safe handling procedures, storage requirements, risk assessment, fuel system maintenance, monitoring, troubleshooting, and emergency response in ammonia-related incidents. The literature also emphasizes the importance of incorporating theoretical knowledge and practical training in these programs to ensure marine engineers are equipped with the necessary expertise and confidence.

The current training landscape offers specialized courses from leading maritime education institutions like DNV Energy Academy, Lloyd's Maritime Academy, and Maritime Training Academy. These courses cover aspects of ammonia as a marine fuel, its value chain, technological advancements, safety considerations, and end-use challenges. However, there is still room for further development of a comprehensive job-training course model that combines theoretical lectures and practical hands-on experiences.

The proposed job training program on ammonia-fuelled propulsion ships aims to fill this gap and address the demands of the maritime industry. The program's theoretical section encompasses essential topics related to ammonia as a marine fuel, while the practical section focuses on hands-on experiences in safe handling, fuel system maintenance, emergency response, and collaborative problem-solving. By undertaking this program, marine engineers will become proficient in operating ammonia-fuelled propulsion ships, contributing to a greener and more responsible maritime future

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author used ChatGPT and QuillBot in order to improve the language and readability. After using these tools/services, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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